NAEB ENGINEERING
COMMITTEE
REPORT #5

THE THEORY OF VIDEO RECORDING

BY
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MARCH, 1954

NATIONAL ASSOCIATION OF EDUCATIONAL BROADCASTERS
14 GREGORY HALL; URBANA, ILLINOIS

(Engineering Committee Report Number 5)

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This paper is intended as a guide to making good video recordings using standard techniques. A complete discussion of the importance of individual parameters of lighting, camera operation, and system alignment can be found in contemporary literature such as the journals of the Institute of Radio Engineers, Society of Motion Picture and Television Engineers and other technical publications. There are also articles covering such items as crispening circuits, gamma correction, linearity, etc. in the literature. Photographic techniques are covered in a variety of sources. Personnel involved in video recording will do well to consult these sources in order to familiarize themselves with the many problems which are not covered in this paper.

BASIC THEORY

The mechanical shutter of a conventional motion-picture camera performs the cyclic tasks of starting, stopping and timing each film exposure. The electronic shutter is an assemblage of electronic circuit blocks which performs these same tasks. It differs from a mechanical shutter in the following respects:

The exposure is started and stopped by successively applying and blanking the picture on the face of the cathode-ray tube, rather than by intervention of a mechanical shutter blade.

The exposure is timed by counting the scanning lines which compose the television picture. Exposure of each film frame is terminated on completion of the 525th scanning line, whether the camera and the television synchronizing generator are in synchronism with each other or not. To achieve the same desirable objective, with a mechanical shutter, two major variables must be controlled. These variables are the operating speed of the shutter and the angular blade width. The angular blade width is fixed in the camera design so that the time of the shutter opening is 525 lines when the shutter is running at nominal operating speed and the synchronizing generator is at nominal frequency. Departure from nominal speed during nonsynchronous operation causes line-count errors. During synchronous operation, momentary changes in power line frequency may cause linecount errors because of the different inertias of the camera mechanism and synchronizing generator.

With either mechanical or electronic timing, the start of exposure must be properly phased in relation to the camera mechanism. Exposure should not start until film pulldown has been completed and the film has become stationary. With a mechanical shutter, this function is performed by the trailing edge of the shutter blade (or the leading edge of the shutter opening). With an electronic

shutter, it is performed by a mechanical cycling disc which generates an electrical cycling pulse suitable for actuating the counting circuits.

The timing method commonly used with either a mechanical or electronic shutter is shown in Fig. 1.

Since four film frames are to be exposed during the period of five television frames, one television frame must be dropped out of every five. By utilizing the interlace feature of the television scan the same result is obtained by dropping one-quarter frame out of every one and one-quarter. One complete field and two complementary portions of adjoining interlaced fields are photographed during a single shutter opening, the separate portions adding up to a single television frame.

Accurate shutter timing is essential for correct operation. The shutter not only blanks the picture during the film motion interval, but also times the exposure to allow exact completion of a single television picture on each film frame. It is this additional timing function that imposes the severe accuracy requirement. With correct shutter timing, the starting line of the first field and the ending line of the third field occupy adjoining positions in the raster.

If the shutter remains open a trifle too long the film records several extra scanning lines, which appear on top of a complete frame as a bright horizontal strip. This strip, either light or dark, becomes an obvious exposure defect which is sometimes called a shutter bar. The region of the picture where shutter closure occurs is known as the join-up or splice.

These conventions apply to a positive print produced from a negative film. The light values reverse for a direct positive print.

It is characteristic of the scanning method that the join-ups of alternate frames have different positions. The two join-up locations are separated from each other by one-half the picture height. In Fig. 1, the intersections of the

dotted lines with the vertical sawteeth indicate the join-ups. The phasing chosen places one join-up near the top of the first and third frames, and the other join-up near the bottom of the second and fourth frames. One join-up can be removed from the picture area by phasing the camera to place the join-up at the raster edge, but the other join-up lies within the picture area. The join-up locations remain stationary when the television and camera rates are synchronized to each other. Otherwise, they travel up or down, depending on the difference between rates. An invisible join-up is a necessity in either case, and shutter timing must be correspondingly accurate. As an illustration of the degree of accuracy required, it may be noted that the edge of a mechanical shutter blade is hand-finished to almost micron dimensions in order to produce a satisfactory join-up. Even with this degree of accuracy, changes in the cyclic time base during nonsynchronous operation cause a shutter bar effect.

A full frame of 525 lines is scanned during the exposure interval. One quarter frame is then dropped during the blanking interval to effect the 5:4 frame rate conversion. Under synchronous conditions, the blanking intervals in lines with an electronic shutter are 131, 131, 131, 132, 131, 131, 131, 132, and so on.

The difference on the fourth count is caused by an accumulation of fractional-line increments to the point where they start the exposure interval a whole line later. Each picture, meanwhile, scans to completion.

On the fourth count, the scan merely starts and ends one line lower. Since the beginning of the blanking interval is tied to the end of the picture, while the end of the blanking interval is tied to the cyclic rate of the camera, the blanking interval is not subject to rigid cyclic control. It can shrink several lines, or increase by any necessary amount. Because of this flexibility, the camera need not be locked to the frequency of the television signal.

The blanking interval of 1/120 second establishes the maximum time allowance for film pulldown, but only a portion of this interval may be utilized. The film must remain stationary during the initial portion of the blanking interval to allow for phosphor persistence effects in the recording cathode-ray tube.

A P11 phosphor is used in the recording cathode-ray tube. The major component of this phosphor's light output is in the blue region of the spectrum where video recording films are most sensitive. This phosphor has a desirably high decay rate, the persistence emission dropping to a very small percentage of initial emission within the scanning time of a few lines.

Persistence emission preserves each line for photographic exposure during an interval after scanning, and supplies an appreciable additional light contribution in relation to initial emission. If the last line scanned in each frame is to contribute its full share of persistence emission before film pulldown starts, the phosphor decay rate must be very high.

The P11 phosphor is almost entirely satisfactory in this respect, but has one shortcoming which seems to be common to all presently available phosphors. Complete extinction requires several seconds. Residual emission from this source causes an exposure difference between the first and last lines. Although the magnitude of this effect is small, the difference can be quite apparent because these lines are adjacent in the recorded picture, and because the high contrast of the photographic film emphasizes any exposure difference.

Compensation is effected quite simply by using a sawtooth waveform which decreases the bias on the cathode-ray tube (increases emission) as the exposure proceeds. The peak amplitude of the compensating sawtooth waveform is adjustable to meet different tube characteristics.

It has been found that vibration, even in a small degree, may betray the location of the picture join-up. The subject for photography is a moving spot

which traces successive patterns of evenly spaced lines. Vibration during film exposure displaces some lines with respect to others, causing line pairing and coarse line structure over portions of the film. Differences in line structure become particularly apparent at the join-up.

The scanning lines should be focused so they are clearly visible over the entire tube face. Any departure from linearity due to the optics of the system should not exceed the widths of two scanning lines. The original film should show definite scanning line resolution in regions of low or medium density, at the corners as well as in the center.

SENSITOMETRY

When a camera is used to take a picture the user has one specific result in mind; a good reproduction. A subjective approach is an uncertain, inconvenient, uneconomical way of obtaining this result. In most cases it is almost impossible to duplicate. The best way is to be able to define the aim objectively in terms of print quality and to obtain results systematically.

A good print, generally speaking, is one in which the full scale of the film is utilized from black to white and in which there is detail in the highlight and shadow regions. A really good print is unobtainable without a good negative. Negative film quality is fundamental.

Sensitometry is the name applied to the measurement of sensitivity and the study of the technical factors affecting the use of film.

In sensitometry the measurements and the language are specific and quantitative. While most of the words are familiar enough many have a special meaning when applied to photography.

Exposure (E) is the total quantity of light energy reaching the film at any particular point. It is the product of the illumination (I) as it reaches the film, and of the time (T) that light is allowed to act on the film. $E = IT$

(where illumination varies with time, Exposure = $\int_0^t$ Idt.). During the time that the film is exposed many different light intensities fall onto the film. This means varied exposures, all of which go to make up the image or negative after development.

Illumination (I) is the amount of light which reaches the film. In the case of a direct positive recording a slightly overexposed film will result in black compression and a slightly underexposed film will result in white compression. Extreme over or underexposure will result in an unusable film.

Time (T) is fixed nominally to 1/30 second.

Density - The result of exposure is, on development, a silver deposit on the film - and this is important. For on its adequacy and on the interrelationship of all the deposits on the film depends the quality of the eventual picture.

This is the mathematical approach to density:

1. Consider a cross section of developed film with a silver deposit "A" as shown in Fig. 2.

2. Suppose the deposit is just enough to permit half the incident light to pass thru.

3. Since the transmission equals the light passed divided by the light incident the transmission is 1/2 or 50%.

4. The reciprocal is called opacity and is equal to 2.

5. The logarithm of opacity is called density and is equal to 0.3.

Both opacity and transmission are clumsy for most photographic computations and, since they are arithmetic proportions, are not directly related to our visual impressions which are logarithmic.

Therefor the term density is freely used in technical discussions.

A sensitometer is any device which produces a series of accurately related exposures. This is required to maintain processing control. A densitometer is required for measuring the densities encountered after exposed film is processed.

By comparing and controlling the relationship between exposure and density in film, remarkable uniformity can be maintained on video recordings.

The Characteristic Curve - on the basis of the above it is possible and useful, to establish exact relationships between exposure and density and to plot these on a graph. For ease in plotting, since density is a logarithmic expression, exposure is transposed into logarithmic terms and becomes known as "log E".

The most common sensitometers consist of a fixed light intensity for a fixed time and a calibrated "wedge" or gray scale as shown in Fig. 3.

The film is exposed to the light transmitted thru the wedge. If the values of light intensity, time, and transmission of the steps in wedge are known the curve shown in Fig. 4 using absolute values for log E can be plotted.

However, relative values can be used if the characteristics of the wedge are known, assigning unity values for the light intensity and time. Most wedges in use today are calibrated so that the light transmission of adjacent steps varies by the square root of 2 or log 0.15.

Because each film has a unique curve and because this curve is used to define the characteristics of films these curves are known as characteristic curves. These curves will also vary if the processing constants are changed, such as developer, developing time, or temperature.

Underexposure results in operation at the toe. Overexposure will result in operation at the shoulder. The straight line portion where density increases uniformly with log exposure is the correct operating range.

Gradient is the slope of a line drawn tangent to the curve at any point. It represents the rate of density growth at that point. Starting from fog level where the gradient is zero and moving to the right the tangent reaches its maximum on the straight line portion where it is called Gamma.

Tests described in other literature have shown that for a wholly acceptable negative, that is, one capable of yielding on excellent print, the minimum exposure must not fall below the point at which the gradient equals .3 of the average gradient. The average gradient is the mathematical average of the gradient values for all the points on the curve between the points of minimum and maximum exposure. This means that at least part of the subject may be located on the toe, with the shadows having moderate contrast and the high lights more contrast. Additional exposure is permissible but not less. Video recording takes advantage of additional exposure to allow more linear reproduction and maximum resolution. However, this rule becomes important when checking sound.

Films should be developed under fixed conditions which control the gamma. These conditions are:

1. Constant temperature
2. Fixed time in developer
   a. For machine processing this means fixed speeds.
3. Fixed concentration of developer

ELECTRICAL FACTORS INFLUENCING EXPOSURE

In the preceding section exposure was defined as the total quantity of light energy reaching the film at any particular point. Since exposure is the product of illumination and time these terms must be examined to determine their effect on the final print. Although we refer to time as equal to 1/30 sec. this is not quite true for either a mechanical or electronic shutter. However, it is a fixed quantity so that it has no effect on this discussion. Illumination is defined as the amount of light which reaches the film in one unit of time.

This infers that the amount of light reaching the film can be controlled. In the case of a video recording this is true in two ways.

First, the aperture of the lens must be set with the following criteria in mind.

1. Sufficient depth of field must be available to bring into focus the entire face of the photographic monitor.
2. A lens has maximum resolution usually one stop for maximum aperture.
3. Operation of the photographic monitor must be such that the video swing does not "bloom" the tube on positive peaks and does not approach cut-off on negative peaks.

Present day equipment permits the use of a lens aperture of f 2.0 to f 3.0

Second, the brightness of the photographic monitor must be set correctly. (Appendix II) It is very important to monitor each of the following parameters which influence brightness in addition to the grid bias.

1. The high voltage should be set correctly.
2. The raster size must be correct.
3. The focus must be correct.
4. The video level must be correct.

The brightness of the photographic monitor, less video, can be monitored by observing and recording the beam current or by external means, such as a light meter or a photocell and microammeter.

THE NEED FOR GAMMA CORRECTION

The films which are made according to the precepts set forth in preceding sections will be good films and represent very nearly the best that can be done photographically. However, let us consider a system in which a negative film is being made in the video recorder and normal prints are made from this negative for projection or rebroadcast. Let us assume that the video signal is linear

with respect to the brightness of the subject. The projected image of this signal will be non-linear with respect to the brightness of the subject unless electrical gamma correction is utilized as described below.

Gamma correction can be provided by an amplifier which has a non-linear amplitude characteristic in the video amplification channel. To meet the requirements for the various non-linear elements in a recording system a variable characteristic such that E out = C (Ein) K, where C is a constant and K is an exponent variable from 0.5 to 2.0, will be found useful. Thus, the output voltage of the unit is a video voltage in which the instantaneous voltage value above the reference black level is a constant times the input voltage raised to some power between 0.5 and 2.0. Graphically this is shown in Fig. 5 where the straight line is Ein and the output is plotted for K = 0.5 and 2.0. It can easily be seen from this statement that if any set up, or pedestal, is in the video signal it should be removed so that only the active picture elements will be affected.

By way of illustration, let us examine the reason for using such an amplifier. We find that in the process of video recording there are the following non-linear elements.

1. The photographic cathode ray tube.
2. The negative film characteristic curve.
3. The positive film characteristic curve.

Confining this examination to the center regions of these curves and disregarding the clipping, or saturation, at the ends we find that the triode power law of the cathode ray tube and the photographic gamma of the two film stocks result in a total picture gamma of approximately 3.5. This response is too high for good reproduction. The poor gray scale and high rate of change from black to white will be unpleasant to the viewer since the average observer likes to see

a picture which has a power in the order of 1.5. To correct this a fractional exponent would be used. In some cases where gamma correction is not used the print is processed to a lower gamma to reduce the overall exponent.

The same principal applies to single film or direct positive recording but the process is slightly different due to the fact that the photographic monitor is now being operated with a signal which drives the tube from some predetermined brightness towards cutoff. In this process we must rely on a graphical analysis or experimental results to determine the overall transfer characteristic which approaches the sum of the exponents at the light gray end of the scale. Thus again a fractional exponent is found desirable to give the finished film more pleasing reproduction.

FILM STANDARDS

There are certain factors which must be strictly observed so that all films will be identical insofar as playback is concerned. These parameters are given below for both 16mm and 35mm in inches:

	16mm	35mm
Picture Location	℄ = 0.315 ± .002 *	℄ = 0.744 ± .002 *
Picture Height	0.285 ± .002	0.612 ± .004
Picture Width	0.380 ± .002	0.816 ± .004
Sound Track Location	℄ = .058 ± .001 *	℄ = 0.243 ± .001 *
Sound Track Width	0.080 ± .001	$0.100 \, {}^{+\,0.000}_{-\,0.008}$

* From guided edge

The aspect ratio for the aperture of a camera is 4.2 x 3 whereas the television aspect ratio is 4 x 3. These have been taken into consideration in the above standards.

A more serious problem to video recording personnel than fixing the electric and processing parameters is the video signal itself. In a general way

there is almost nothing the recording personnel can do unless they receive the co-operation of the video operators, master control, and lighting personnel.

The following statements may seem arbitrary but they are offered with the realization that circumstances alter cases. However, whenever possible strict adherance to these rules will make remarkable improvements.

The image orthicon camera chains should be matched as closely as possible for:

1. Blanking time, both horizontal and vertical
2. The iris should be set for operation on the straight line portion of the image orthicon characteristic curve. If electrical iris control can be provided this should be done.
3. The target voltage should be set for best gray scale rendition on a test pattern at the light level to be used <u>and left alone</u>.
4. Aspect ratio, linearity, streaking, trailing white, etc. should all be corrected just prior to recording time.

The video operator should maintain his output very rigidly, using a 5" waveform monitor, if necessary. He should <u>never</u> change gain after the camera is "on the air".

Master control must maintain the pedestal level as closely as possible.

The lighting men should attempt to keep lighting on subjects where detail is required within a 30-1 contrast ratio. Standard practice might be to try 25-1 to keep the subject matter requiring detail closer to the straight line portion of the image orthicon characteristic curve. (see Bibliography)

SOUND

It is impossible to discuss the entire field of sound reproduction on film and yet it is very necessary that the user of the GPL video recording camera understand this subject if the finished recording is to include the reproduction of sound.

Certain terms are defined below which are met in video recording. It must be assumed here that the audio system up to the input is of optimum quality. However the actual operator should never take this for granted but should check distortion, noise level, and frequency response, at regular intervals. It must also be assumed that the projector, or other reproducing equipment is adjusted for optimum quality. The sound head on the projector should be checked regularly for:

1. Sound focus
2. Track position
3. Azimuth
4. Flutter
5. "wow"

Imperfect reproduction will have exactly the same effect as imperfect recordings since the parameters are the same.

A sound track on film should have good frequency response, low distortion, low noise level, negligible wow and flutter, and must be positioned correctly.

Frequency response of the GPL video recording camera is essentially flat to 7000 cycles. Procedures for checking focus and azimuth, and for checking the frequency are set forth in the instruction section on the J. A. Maurer system. Frequency response can be affected somewhat by the quality of the developer used.

The noise level of a film is controlled by the AGN, or bias. The Anti Ground Noise circuit provides a fixed exposure on the sound track with no modulation present which represents the average density of a 100% modulated track. With modulation present this exposure is inversely proportional to the signal so that at approximately 100% modulation there is no bias. This prevents the grain structure in the film emulsion from generating a noise signal.

For example, Eastman Kodak Type 7302 film exposed and processed for minimum distortion inthe GPL video recording camera will have a density of 0.3 with no modulation and no AGN. When the galvo is correctly biased with the AGN current, still no modulation, this density will be approximately 0.5.

The distortion is usually measured in terms of intermodulation since standard distortion tests may be made inaccurate due to noise signals being larger than the harmonic distortion to be measured. Intermodulation testing consists of using a low frequency signal added to a high frequency signal in a 4:1 ratio. After recording on film and the processing the signal is reproduced. The signal at the output is fed to two attenuators which discriminate against the two original frequencies. If the system is non-linear in any way, intermodulation will occur between the two signals, giving rise to sum and difference or harmonic frequencies which will pass through the filters. The intermodulation frequencies are then measured and read as a percentage of the total output. The harmonic distortion may be determined graphically but is usually considered to be numerically about one-quarter of the intermodulation figure.

Measurements of this type are also influenced by the reproduction equipment used in the tests. Therefore, it is important that these measurements be made only with reproduction equipment known to be free from such defects as wow, flutter, variations in speed or excessive distortion.

The preceeding brief discussion is not intended to make it possible to obtain good sound recordings but is intended only to introduce a subject which should be completely understood by personnel operating the recording equipment.

The assistance of F. N. Gillette, F. S. Dellenbaugh, and many others is gratefully acknowledged.

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Appendix One

Test Strip Method of Setting Up the Video Recorder

In order to check focus and picture position when setting up a recorder and for routine daily checks which do not require accurate photographic processing, the test strip scheme is recommended.

The equipment is run in a normal manner for ten or fifteen seconds and then shut off. With the room lights off, using only red safelight, the take-up magazine is opened and 2 or 3 feet of exposed film is removed by breaking the film.

This test strip may be developed, fixed, and washed in small open tanks or beakers and then dried in front of an electric fan. For quick processing, the following chemicals are suggested:

Developer - Eastman Kodak D-8 stock solution

Takes 1-3 minutes @ 68° F.

Fixer - Eastman Kodak F-7

Takes about 30 seconds @ room temperature.

Lights may be turned on after film clears.

The test strip may be examined with a microscope of 20-40 power.

Appendix Two

A good video recording must utilize the straight line portion of the film characteristic curve from black to white and must have detail in the highlight and shadow regions. In order to meet the requirements of this general statement the actual video signal must be of optimum quality.

In case of a direct positive recording the characteristic curve of the positive recording film stock to be used must be determined. For the purpose of explanation a curve is shown in Fig. 6. Methods for obtaining this curve are discussed in a previous section.

Point A is the point on the toe which has been determined as the point of minimum exposure for video recording. The density at this point is 0.2 and the transmission is approximately 63%. To satisfactorily expose the film and duplicate the contrast ratio of the video signal, a transmission of 2% or less must be used which give us a maximum density of approximately 1.7. However, it is general practice to increase this density to approximately 2.0 or point B.

The electrical parameters which will expose the film over this range must be determined. Therefore, a curve of Density vs. Grid Voltage (Eg) similar to that shown in Fig. 8 must be constructed, with the exception that a positive film stock must be used, such as Eastman Kodak 7302. This curve is made by exposing strips of film to the photographic monitor at different grid voltages (a defocused raster with zero video gain) and processing this strip at the same gamma as that used for obtaining the characteristic curve. Be sure to record the beam current of the photographic monitor for future use.

Note

> It is very important to monitor each of the following parameters which influence brightness in addition to the grid bias:

From this curve select the grid voltage which results in a density of 2.0. Note the corresponding value of beam current so that the display tube can always be set for the same brightness. This will be the black level of the film. Now compute the difference in grid voltage between the two densities of 0.2 and 2.0. This will be the required grid drive for the photographic monitor to correctly expose the film. These densities compensate for normal set-up in the video signal. If set-up has been removed use 1.8 as the maximum density.

This entire procedure must be repeated from time to time so that changes which occur in meter readings, aging or change of the photographic monitor, can be corrected.

In the case of a negative recording we must repeat the steps described above using a negative recording film stock. First determine the characteristic curve of the film stock at the selected gamma as shown in Fig. 3.

Point A represents a density of .3 which is considered a good minimum density for obtaining a negative recording. Printing this gray scale on the same stock as used for Fig. 6 at several light values should enable us to match Point A of the negative stock to Point B of the positive stock. A plot as shown in Fig. 7 will then give us Point B for the negative stock by geometrical transition from the positive stock back to the negative stock. This will be very close to 1.3.

<u>Note</u>

> The slope of the transition line will vary for different printing light values but will always have the same point of origin.

Now that Points A and B for the negative film stock are known, a plot is made of density vs. grid voltage. The black level (.3) and the video drive necessary to reach the white level (1.3) are found as in Fig. 8.

Subsequent prints should be made with the value of printing light found above.

It should be noted that if minor errors are made by the operator, or by master control, in setting black level or video swing that they can be corrected by changing the printing light. In cases of this nature the negative is "notched" so that reprints will be identical. Standard procedure by film laboratories, for example, is to print facial characteristics on a medium closeup to a density of 0.8 for a man and 0.6 for a woman in the absence of other instructions.

A check sheet for each kind should be made at the time the picture is recorded and then the details rechecked on the print so that data is available for each negative made.

Scanned from the National Association of Educational Broadcasters Records
at the Wisconsin Historical Society as part of
"Unlocking the Airwaves: Revitalizing an Early Public and Educational Radio Collection."

A collaboration among the Maryland Institute for Technology in the Humanities,
University of Wisconsin-Madison Department of Communication Arts,
and Wisconsin Historical Society.

Supported by a Humanities Collections and Reference Resources grant from
the National Endowment for the Humanities